
**Trial Sections with Polymer-Modified
Asphalt Cement at Port Hope
(Contract 87-32)**



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Technical Report Documentation Page**Trial Sections with Polymer-Modified
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Abstract:	This construction report describes and documents the design and installation of field trial sections with polymer-modified asphalt cement on Highway 401 near Port Hope, Ontario. Included are descriptions of the pavement rutting problem and its conceived solutions, the polymer additives proposed and used on the test site, field trial design, construction procedures, and material testing results. The field trial demonstrated the viability of full-scale construction with four different polymer-modified asphalt cements and provided an opportunity to test these new materials and to verify the claimed rutting resistance of such polymer-modified mixes. Field performance test data, such as rutting resistance and low temperature behaviour will be reported at a later date. Based on the findings and experience gained in the field trial, it is recommended that: a) the minimum liquid asphalt cement temperature be 140°C and adequate heating and circulating facilities be implemented, b) specification and quality control methods be developed, and c) the performance of the trial section be evaluated for at least 3 years.
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1. INTRODUCTION

The Research and Development Branch initiated Project 21165 in 1986 to conduct field trials of asphalt mixes with high rutting resistance. After several potential test sites were reviewed with Central Region engineers, approval was given to proceed with the construction of five test sections on Highway 401 near Port Hope, as part of the Ontario Ministry of Transportation's Contract 87-32.

This construction report documents in the following sections the field trial construction, including a description of the pavement rutting problem and its conceived solution, the additives, the test site, field trial design, construction procedures, and material testing results.

The construction of the test section was completed on June 19, 1987. All construction and laboratory test data have been collected and included in this report. Field performance test data, such as rutting resistance and low temperature behaviour, will be reported separately at a later date.

2. PROJECT OVERVIEW

2.1 The Rutting Problem

Demands placed on pavements in terms of traffic volume, and increase and type of loading has risen markedly in the past 15 years. A direct result experienced in Ontario is significant rutting damage showing up especially in heavy truck traffic locations (1). The rutting pattern is now changed from a smooth depression in each wheel path, to double ruts with steep shoulders in each wheel path. Cars with excessive slack in steering mechanisms can experience transient lack of lateral control when they wander across these double ruts.

Furthermore, hydroplaning may occur when water accumulates in the rut. This rutting damage appears in the upper layers of the pavement and is more severe in mixes made with rounded aggregates.

The change in the pattern of ruts is believed to be due to the shift from bias ply to radial ply tires. The shift from bias ply to radial ply tires is accompanied by an increase in tire pressures from about 85 psi to about 110 psi. Theoretical analyses show high probability of increased damage to upper pavement layers due to higher tire pressures. The trucking industry benefits from a change to radial tires and higher tire pressures. In addition to increased load capacity, radial tires give better tire durability, better fuel economy, improved maintenance costs, and reduced downtime in the retread cycle (2).

Similar rutting problems are also reported by the Provinces of Quebec and Saskatchewan (3,4). A review of the impact of tire type and inflation pressure has been conducted and reported by Papagianakis and Haas (5,6).

2.2 Proposed Solutions and Objectives

One recognized solution to rutting deformation is the use of 100 percent crushed coarse and fine aggregates in asphalt mixes. This principle has been accepted for implementation. However, there may, in addition to cost and availability considerations, be problems associated with 100 percent crushed mixes, such as workability and compaction. These problems may be resolved by using some rounded aggregate.

gate with or without additives in the asphalt binder which improve the rutting resistance particularly at elevated temperatures. Several additives have been used elsewhere with success (7-10).

The objective of a field trial is to demonstrate full-scale construction of trial sections with several different polymer additives on a major highway in Ontario, to acquire expertise and experience in handling and testing of these new materials, and to verify the claimed rutting resistance of such modified mixes. The performance of the test section will be compared with results from a control test section. In addition to rutting resistance, other properties must be carefully monitored to confirm that none has been adversely affected by the addition of polymer, e.g. low temperature cracking resistance. A modest increase in service-life could have a marked impact on MTO expenditures, which are over \$260 million for construction and \$180 million for pavement maintenance annually.

3. ASPHALT ADDITIVES AND SUPPLIERS

Asphalt modifiers have been promoted and applied for over 50 years, but were only seriously considered after the asphalt cement price had risen by a factor of five since 1973. At these asphalt cement prices, modifiers may be worth their high cost and could be justified provided they can significantly improve pavement performance.

To date, the European technology in rubber and plastic modifiers appears to be advanced over the North American experience. But since 1980, almost every major US and Canadian chemical firm and several universities have active research projects on asphalt modifiers.

The classes of additives considered for this project are plastics (e.g. polyethylene) and block copolymer rubbers (e.g. styrene-butadiene-styrene). The prime goal for the addition of these additives is to increase the stiffness at high ambient temperatures in order to reduce the pavement tendency to rut and shove, and, at the same time, control or reduce its tendency to crack due to brittleness and the binders cold weather stiffness. An overview of consistency over a wide range of temperature is given in Figure 1 adapted from Epps (10). Shown are the asphalt binder viscosity changes with temperature extending from low service temperature to pumping and mixing temperatures. A more detailed description of recent asphalt-modifier studies and modified asphalt binder characteristics has been published by several researchers including Little et al, Texas A & M (11,12), Terrel and Walter, Pavement Technologies Inc. (17), King et al, Elf Aquitaine (13-15), Moran, Imperial Oil (16), Woodhams et al, University of Toronto (17-19), Felsinger et al, Novophalt (20-22), Shuler et al, New Mexico Engineering Research Institute (23,24), and Downes, Shell International (25).

The additives and the blending or compounding technology was supplied by the following:

<u>Supplier</u>	<u>Additive</u>
Esso Petroleum Canada Toronto, Ontario	"A" Engineering Bitumen Type 306
Shell Canada Chemical Co. North York, Ontario	"B" Kraton 4460
McAsphalt Industries Ltd.* West Hill, Ontario	"C" Styrelf
RSR Inc.** Milliken, Ontario	"D" Polyethylene

* now Polymac Engineered Asphalt Corp. in partnership with
Elf Canada Ltd.

** in cooperation with Prof. R. Woodham, University of Toronto.

The asphalt cement used in this field trial and modified with various polymer additives was a 85-100 PEN paving asphalt from Petro-Canada's Clarkson Refinery. The characteristics of this asphalt cement and samples thereof modified with polymer additives are summarized in Table 1.

The penetration of 82 for the "original" asphalt (i.e. asphalt cement used in the control section) is low and does not meet the specification of 85 Pen minimum. The test results obtained by different laboratories for the same test sample of unmodified, "original" asphalt cement are fairly close. However, some data obtained by the same laboratories for the modified asphalt cements show significant differences. Possible reasons for this observation could be one or more of the following:

- limited stability of the polymer dispersion in asphalt cement;
- lack of experience in testing materials with the given physical properties;
- inadequacy of the standard rheological test procedures (e.g. kinematic viscosity).

The observed rheological changes are similar to the findings reported by other investigators (11-15). All tested additives increase the high temperature viscosity and decrease the penetration. This resulting increase in asphalt stiffness in the high temperature service range (see Figure 1) would tend to increase resistance to rutting.

More consistent test data on the modified asphalt cements is required to make sound deductions regarding the additives ability to decrease the temperature susceptibility of the asphalt cement. In any case, low temperature asphalt cement stiffness predictions, based on parameters such as the penetration index or the penetration viscosity number should not be used alone, but substantiated by testing the low temperature properties of the corresponding modified asphalt concrete mixtures (11,12).

Test results for elastic recovery, tenacity, and toughness of samples of recovered asphalt and modified asphalt cements are given in Table 2. The test methods were developed for rubberized asphalts. The elastic recovery test method was carried out by means of the ductilometer, i.e. ASTM D113-79. A tentative method of the test proposed by Benson (27) was used to determine the toughness and tenacity. Additional experiments using the technique of force ductility measurements are planned. This will hopefully, explain the differences in test results shown in Table 1 and assist in the interpretation and correlation to field performance.

4. FIELD TRIAL DESIGN

4.1 Test Site Description

The test site is located on Highway 401 near Port Hope and is part of the resurfacing and rehabilitation Contract No. 87-32. The project location map is given in Figure 2. The main considerations for this selection were:

- 1) a typical situation of heavy traffic induced rutting;
- 2) uniformity and strength of base to exclude the influence of the underlying base on the rutting; and
- 3) easy accessibility for performance evaluation.

Details of performance and condition of the pavement as it existed prior to rehabilitation are given in the Soils Design Report (27). Severe wheel track rutting is reported, predominantly in the east and west bound driving lanes. The traffic load in both directions ranges from 26,000-28,000 AADT with about 17-25% commercial vehicles. Examples of typical severe wheel track ruttings are shown on Figure 3. These severe rutting conditions are essentially the result of the lateral squeeze or plastic flow of low stability asphalt courses caused by high volumes of truck traffic, particularly in the eastbound direction.

Additional modes of distress shown in the pavement performance and condition survey carried out in June 1986 include:

- intermittent sections with moderate to severe longitudinal cracks,
- intermittent transverse cracks,
- a few sections with severe alligator cracks.

Examples of typical transverse cracking and severe pavement distress are illustrated by the photographs presented in Figure 4. A condition survey of the pavement surface from Station 3+500 to Station 6+100 (see Appendix I) was carried out on May 19, 1987 immediately prior to the pavement rehabilitation.

The existing pavement structure consists of an average of 230 mm hot mix over 550 mm granular material. The thickness and strength of the base suggest that rutting cannot be attributed to base or subgrade failure. In order to establish the uniformity and strength of the base and thereby preclude the influence of the base on the ruttings phenomenon, deflection measurements were made every 30 m throughout the 2.6 km test site.

A Falling Weight Deflectometer (FWD) was used for the testing program which was carried out immediately prior to the rehabilitation work. The normalized FWD Deflections versus Roadway Chainage for both the inner and outer wheelpath is shown in Figure 5. The mean deflections of 0.15 mm and 0.18 mm for the inner and outer wheelpath respectively are considered quite acceptable and in line with the design and intended application.

Finally, the interim rehabilitation treatment selected for this project was the partial pavement removal of 90 mm followed by resurfacing with 50 mm HL1 hot mix binder course and 40 mm HL1 hot mix surface course. This design is expected to remedy the present rutting condition and defer the need for full rehabilitation, which is scheduled for the 1990's.

4.2 Layout of Test Sections

The location of the test sections within Contract No. 87-32 was to some extent, determined by the construction procedure. The rehabilitation work on this contract involved cold milling two lifts of the rutted driving lane and passing lane as shown in Figure 6, and replacing with 2 lifts of hot mix. For the resurfacing, the contract specified recycled HL1 hot mix, 25/75 reclaimed to virgin. However, in order to allow sufficient time to produce the mix design for the recycled mix, a modified HL1 hot mix was specified which would use only virgin aggregates between the Stations 3+500 and 6+100 on the eastbound driving lane (Figure 6).

This location was selected to accommodate four test sections with modified asphalt cement and one control test section with original paving asphalt cement as shown in the trial section layout, Figure 7. The layout was kept simple by choosing the same original 85-100 Pen

asphalt cement and aggregate mix for all test sections. The length of 500 m for each test section is considered adequate to obtain reliable construction experience and representative field performance data.

4.3 Mix Design

The granular materials used for this project were 3M Canada Ltd. traprock coarse aggregate (3M Havelock, C1-54) and TRT washed concrete sand (TRT 52-24-0). Manufactured 3M traprock fines were initially also considered for blends of the fine aggregate portion in ratios of 1:1 and 1:3 of 3M traprock fines and TRT sand respectively, but these were not used.

One objective of the mix design for this field trial was to produce a proven HL1 modified hot mix which would best demonstrate the effectiveness of the polymer additives within an acceptable time period. This was achieved by choosing air voids, Marshall flow and Marshall stability to produce a mix which is designed slightly below the optimum with respect to rutting resistance.

The selected aggregate blend of 50/50 (% volume) 3M Havelock coarse aggregate and TRT sand had Marshall test characteristics which is expected to show moderate rutting over a period of 1-3 years based on experience with similar mixes on Highway 401. The mix design test data is summarized in Table 3 and the grading chart of the granular materials is shown in Figure 8. The sieve analysis shows that the TRT sand, which is a washed concrete sand, meets the Ministry's fine aggregate specification. The amount of the combined mix passing 75 μ m size is 0.9%.

5. CONSTRUCTION

5.1 Mix Production

The construction of the field trial sections with modified asphalt cement including mix production was carried out by Harnden and King Construction of Cobourg, Ontario as part of Contract 87-32. The asphalt concrete mix plant was a portable Cedarapids Model 8828 drum mixer, 400 tph capacity, which was located at Pit No. 22 in the Pontypool-Mosport area off Regional Road 20.

The original (not modified) asphalt cement was kept in a storage tank at the asphalt plant. The polymer modified asphalt cements were delivered in separate, dedicated tankers to the plant and stationed alongside the asphalt storage tank. The hot oil jacketed metering pump system of the asphalt plant and 3 inch diameter flexible hose were used to deliver the modified asphalt cements directly from the tanker to the mixing drum when required. Between test runs with different additives, the pumping system was flushed and drained properly. This procedure of handling four different additive systems in a trial installation proved to be acceptable as long as the asphalt cement temperature was high enough for pumping. Furthermore, there was no visible evidence of phase separation between asphalt and polymer additives.

Because of higher viscosities of most polymer modified asphalts, a handling and pumping temperature of 140-150°C (approximately 280-300°F) is strongly recommended. Several tank loads of modified asphalt cements had to be turned back for reheating before they could be off-loaded. In some instances the safety-overload of the asphalt metering pump was by-passed to avoid shut down due to viscous slugs of modified asphalt cement from cold spots such as the bottom of the tanker. The observed starving of the metering pump loop is likely the main cause for the low asphalt content in several mixes laid in the first lift (binder course). The field trial, therefore, has clearly demonstrated that modified asphalt cements are with regard to handling and pumping at marginally low liquid temperatures less forgiving than the original, unmodified asphalt.

Figure 9 depicts a crude example for "force ductility" for a polymer modified asphalt cement. The photograph shows an attempt to pick up a spill from opening a frozen tanker valve and demonstrates the consistency of the semi-solid binder.

The hot mix production in the drum-dryer mixer was carried out under normal operating conditions. The mixing temperature of 140-150°C was controlled by a thermocouple at the exit of the drum, immediately prior to the conveyor carrying the hot mix to the holding bin. The hot mix made with modified asphalt cements handled and appeared normal. No unusual observations were made with respect to coating of the aggregate, odour, or emission, colour, flow, etc. for any of the additives used during this field trial.

5.2 Laying Procedure

The paving operations were carried out on June 16, 17, and 19, 1987. The paving schedule for both lifts, i.e., the 50 mm binder course and the 40 mm surface course is summarized in Table 4. Delivery of modified asphalts at unacceptable low temperatures delayed the completion of two test sections until June 19, 1987.

A Barber-Greene SA150 finisher was used for laying the hot mix. For compacting, a Dynapac CC42R vibratory steel wheel roller (Figure 10) carried out the initial breakdown followed by a Dynapac CP21 rubber-tired roller. The paving procedure was the same as with conventional asphalt hot mixes. No problems were encountered with the exception of some minor asphalt mix pick-up by the rubber-tired roller. This problem of asphalt mix pick-up, however, was resolved by keeping the rubber-tired roller further back and allowing the surface of the mat to cool somewhat more before putting the finishing roller on it. The ambient temperatures (daily high) during paving operations ranged from 21-28°C.

The field trials have shown that the introduction of the polymer modified asphalt cement does not require any significant changes or precautions for the traditional hot mix paving procedure.

5.3 On-Site Quality Control and Sampling

Hot mix quality control and acceptance testing was carried out in a mobile field laboratory by Trow Inc. on behalf of the contractor. Several hot mix field Marshall checks were also carried out by the Ministry's own mobile laboratory. The on-site field data is summarized on Tables 5 and 6. Several mixes with low asphalt content were recorded during the laying of the first lift, i.e., binder course.

A few spot checks on asphalt cement penetration and softening point were also carried out by staff of the Research and Development Branch, who also monitored the construction procedure including mix temperature and compaction.

Representative test samples of aggregates, asphalt cement, modified asphalts, and their respective hot mixes were taken at the time of mix production of each test section during the construction of the surface course. The binder samples were taken directly from each tanker. The hot mix samples were obtained from the conveyor at the exit of the drum mixer. These test samples were also made available to the suppliers of asphalt and modified asphalt cement used in this field trial.

6. CONSTRUCTION TEST RESULTS

Hot mix samples of all test sections taken during the construction of the surface course were recompact and tested independently by several laboratories. The Marshall test data is summarized in Table 7. The variation of results between the various laboratories is within the expected tolerances. The hot mix sample taken for test section 3 shows a low binder content, i.e., 1% below design. The Marshall stabilities of the modified asphalt hot mixes are slightly, but not significantly, higher than the hot mix of the control test section 1. All other Marshall test data including the gradation of the extracted aggregate shown in Table 8 meet essentially the selected mix design criteria.

Upon completion of the construction, three cores of 6 inch diameter were taken from each test section to check the quality of compaction. A description of the core, the bulk relative densities and the degree of compaction is given in Table 9. These results are essentially within the tolerances and expectations for employed procedures and practices.

Based on these results and considering the constraints and circumstances of the project, the construction of the test sections was accepted. Additional testing such as skid resistance, resilient modulus, low temperature mix stiffness, etc. are planned for inclusion in a future field trial performance report.

CONCLUSIONS

The field trial demonstrated full-scale construction of test sections with four different polymer modified asphalt cement and provided an opportunity to test these new materials and to verify the claimed rutting resistance of such modified mixes.

Construction experiences and main conclusions are summarized in the following:

1. The construction of trial sections with four polymer modified asphalt cement was successful and could be carried out in the conventional manner.
2. Polymer modified asphalt cements are with regard to pumping and metering at marginally low liquid temperatures less forgiving than the original, unmodified asphalt, e.g., formation of viscous slug at cold spots. A temperature of 140-150°C will facilitate handling and pumping.
3. All polymer additives and asphalt cement admixtures appeared stable for the duration of construction.
4. Compacting of modified asphalt hot mix with a rubber-tired roller indicated a tendency to "pick-up" which could be avoided by allowing more time for the surface of the mat to cool.
5. The constructed trial sections meet the pavement design specification with the exception of a few hot mix samples, mostly from the binder course, which tested low in asphalt content. The low binder content is attributed to metering problems at the plant due to cold delivered, modified asphalt cement.
6. Polymer modified asphalt pavements can be produced and constructed without significant changes to mix production and paving procedures.

RECOMMENDATIONS

Based on the findings and experiences gained from the field trial, the following recommendations are made for consideration of future application and testing:

1. For the construction of future trial sections, the contract should specify a minimum liquid asphalt temperature of 140°C and the contractor should have adequate mixing (circulation via oil-jacketed pipe) and heating facilities to avoid delays due to cold binder.
2. For the selection of future test sites, areas with intersection or changes in pavement width should be avoided. This will improve the control over the construction procedure, e.g., uniformity of compaction pattern, and also the safety of the crew.
3. Specification and quality control tests for polymer modified mixes should be developed.
4. The effect of polymer additives on critical paving mix characteristics, especially low temperature properties should be evaluated in order to properly assess the net benefit of improving the rutting resistance.
5. The performance of the trial sections should be monitored for at least 3 years. The performance tests should include rutting depth, skid resistance, ravelling, and cracking.

REFERENCES

1. Tam, K.K., and Lynch, D.F., "Ontario Freeway Rutting Investigation", Ontario Ministry of Transportation, Presentation at the RTAC Workshop on Rutting, Toronto, September 28, 1986.
2. Charles, F.S., "Trends in Truck Tires", Goodyear Presentation at the RTAC Annual Conference, Toronto, September 28, 1986.
3. Vallieres, A., Lavignes, G., and Desmeules, H., "Rut Formation on Asphalt Road Surfaces - Scope of the Phenomenon and Objectives", Quebec Ministere des Transport, Presentation at the RTAC Workshop, Toronto, September 28, 1986.
4. Huber, G.A., and Heiman, G.H., "Effect of Asphalt Concrete Parameters on Rutting Performance: A Field Investigation", Saskatchewan Transportation, Presentation of the RTAC Workshop on Rutting, Toronto, September 28, 1986.
5. Papagianakis, A.T., and Haas, R.C.G., "Wide-Base Truck Tires: Industry Trends and State of Knowledge of Their Impact on Pavements", Report prepared for the Ontario Ministry of Transportation under OJT & CRP Project 21160, December 31, 1986.
6. Haas, R.C.G., and Papagianakis, A.T., "Understanding Pavement Rutting", Presentation to the RTAC Workshop, Toronto, September 28, 1986.
7. Terrel, R.L., and Walker, J.Z., "Modified Asphalt Pavement Materials - The European Experience", AAPT Proceedings, Vol. 55, 1986.
8. Bass, D.A., "Experiences with Latex in HMA", Texas State Department of Highways and Public Transportation, Experimental Project Report No. 631-2, September 1985.

9. Kay, B.J., "Rubber Latex Asphalt", Utah Department of Transportation, Memorandum, October 23, 1985.
10. Epps, J., "Asphalt Pavement Modifiers", Civil Engineering, ASCE. April 1986.
11. Little, D.N. et al, "Investigation of Asphalt Additives", FHWA Research Report No. RD-87/001, November 1986.
12. Little, D.N. et al, "Mechanistic Evaluation of Selected Asphalt Additives", Texas A & M. Prepared of Publication by AAPT, December 1986 (Synopsis published only).
13. King, G.N., and King, H.W., "Polymer Modified Asphalts - An Overview", Proceedings Highway Division, ASCE, Atlanta, Georgia, May 19-21, 1986.
14. King, G.N. et al, "The Improved Rheological Properties of Polymer Modified Asphalts", ASTM Symposium, Nashville, TN, December 11, 1985.
15. King, G.N. et al, "Polymer Modification: Binder's Effect on Mix Properties", AAPT Proceedings, Vol. 55, p. 519, February 1986.
16. Moran, L.E., "Compatibility - The Key to Modified Asphalt Performance", Proc. CTAA.
17. Woodhams, R.T. et al, "Chemically Modified Asphalts for Improved Wet Strength Retention", I & EC Product Research and Development, Vol. 18, p. 86, June 1979.
18. Woodhams, R.T. et al, "Polyethylene - Modified Bitumen for Paving Applications", J. of Applied Polymer Science, Vol. 31, 2685-2704, 1986.

19. Woodhams, R.T. et al, "Polyethylene-Modified Bitumen for Paving Applications", AAPT Proceedings, Vol. 55, p. 541, February 1986.
20. Felsing, R.A.M. et al, "Novophalt Seminar", Proceedings NATO Infrastructure Seminar, Oslo, March 12, 1986.
21. Denning, J.H., and Carswell, J., "Assessment of "Novophalt" as Binder for Rolled Asphalt Wearing Course", TRRL Research Report No. LR 1101.
22. Pearson, D.C., "Resistance to Deformation of Asphaltic Concrete With Novophalt Binder", TRRL Materials Memorandum No. 125, 1985.
23. Shuler, T.S., "Polymer Modified Asphalt Properties Related to Asphalt Concrete Performance", ASTM Symposium, Nashville, TN, December 1985.
24. Shuler, T.S., "Executive Summary of Asphalt Additives", New Mexico Research Institute, Alburquerque, NM, July 1986.
25. Downes, J.W., "Modified Binders to the Year 2000", 6th International Asphalt Conference, Sydney, Australia, January 27-30, 1986.
26. Benson, J.R., "New Concepts for Rubberized Asphalts", Roads and Streets, April 1955.
27. Shibuya, G., and Mullett, D.A., "Soils Design Report", Work Project 77-84-01, Ministry of Transportation and Communications, Geotechnical Section, August 21, 1986.

TABLE 2: RHEOLOGY TEST DATA

Test Section Asphalt Type (1)	1 5-100 Pen control Petro-Canada	2 85-100 Pen modified Esso	3 85-100 Pen modified Shell	4 85-100 Pen modified McAsphalt	5 85-100 Pen modified RSR
Supplier					
Method of Test:					
- Elastic Recovery (%)	failed	failed	80	75.0	21 (2)
- Toughness (In. lb.)	53.6	(3)	93.4	149.2	60.5
- Tenacity (In. lb.)	9.1	(3)	57.0	80.4	2.9
- Toughness/Tenacity	5.89	(3)	1.64	1.86	20.9

NOTES:

- (1) Sample recovered from hot mix
- (2) Sample was stretched only 19 cm
- (3) Not determined, maximum load greater than 100 lb.

TABLE 3: MIX DESIGN TEST DATA

Test	HL1 Modified Hot Mix			
	A (selected)	B	C	Spec.
Specific Gravity*				
- bulk	2.498			
- maximum	2.579			
Air Voids, % vol	3.8	6.5	2.4	3 - 5
VMAs, % vol	15.7	15.7	15.7	
Marshall Stability, N**	9861	9815	8820	8900 min.
Marshall Flow, 0.25 mm	8.0	6.8	9.4	8.0
Asphalt Content, % wt	5.0	4.5	5.5	

* 50/50 (% vol) 3M Havelock/TRT sand

** At 60°C, 60 blows, (mechanical bevelled hammer) each face

TABLE 4: PAVING SCHEDULE

Date of Paving	June 16-17, 1988 Binder Course				June 17, 1988 Surface Course				June 19, 1988 Surface Course			
	Station	Time	Mix Temperature (°C)	Station	Time	Mix Temperature (°C)	Station	Time	Station	Time	Mix Temperature (°C)	
Test Section												
1. Control	3+500	10:30 am	130				3+500	11:30 am			130	
2. Esso	4+070	1:30 pm	130					delayed to -->	4+115	7:15 am		125
3. Shell	4+590	4:15 pm	127				4+590	2:15 pm			125	
4. McAsphalt	5+040	8:00 pm	125				5+100	3:30 pm			125	
5. RSR	5+520	8:00 am	125					delayed to -->	5+620	9:00 am		130

TABLE 5: ON-SITE TEST OF GRADATION

Sample I.D.	Date Sampled	Location/ Station	Lab*	9.5	6.7	4.75	2.36	1.18	600	300	150	75
				mm	mm	mm	mm	mm	µm	µm	µm	µm
Mix Design (87-02-079)	187 06 12	Hwy 401	HO	18		52.4	59.0	65.0	73.0	86.0	96.0	99.1
Trial Batch	187 06 15	Plant	MTC	20.3		53.7	59.3	64.7	74.1	89.4	97.1	96.9
1 (control)	187 06 16	3 + 608.5	Trow	19.2		50.4	56.9	63.0	74.1	90.3	97.4	99.3
		3 + 608.5	MTC	19.1		45.0	53.1	60.2	71.4	88.6	96.9	98.8
	187 06 17	Road	HO	16.0	37.0	48.3	55.0	61.0	72.0	88.0	96.0	98.9
2 (Esso)	187 06 19	Plant	HO	20.0	40.0	50.9	59.0	65.0	74.0	88.0	96.0	99.0
3 (Shell)	187 06 17	4 + 700	MTC	20.0		53.3	60.2	65.6	73.7	89.4	97.6	98.9
		4 + 900	MTC	23.5		57.8	63.6	68.2	76.3	83.5	96.9	98.9
		Plant	HO	18.0	39.0	50.5	57.0	63.0	73.0	89.0	96.0	98.9
4 (McAsphalt)	187 06 17	5 + 006	Trow	23.5		55.6	61.3	66.3	75.6	90.2	97.3	99.1
		5 + 416	MTC	18.8		51.3	57.7	63.8	74.8	91.1	98.0	99.4
		Plant	HO	16.0	40.0	49.8	58.0	64.0	74.0	88.0	96.0	98.8
5 (RSR)	187 06 17	5 + 614	Trow	19.0		51.5	58.1	63.7	74.3	89.9	97.3	99.2
		5 + 970	Trow	25.1		58.1	63.4	68.4	77.2	90.5	97.3	99.0
		5 + 970	MTC			56.8	62.8	68.1	77.2	91.5	98.0	99.6
	187 06 19	5 + 629	Trow	22.3		54.9	61.4	66.8	76.1	89.9	97.2	99.2
		Plant	HO	17.0	37.0	49.3	56.0	62.0	72.0	89.0	96.0	98.8

* Laboratories: HO - Head Office, Downsview, MTO - on-site mobile; Trow - on-site mobile

TABLE 6: ON-SITE MARSHALL TEST DATA

Sample I.D.	Date Sampled	Location/ Station	Lab*	BRD	MRD	Voids (%)	VMA (%)	AC (%)	Stability (N)	Flow (0.25 mm)
Mix Design (87-02-079)	87 06 12	Hwy 401	HO	2.498	2.601	3.8	15.7	5.00	9861	7.8
Trial Batch	87 06 15	Plant	MTC	2.471	2.577	4.1	17.0	5.30	7866	9.4
1 (control)	87 06 16	3 + 608.5	Trow					5.01		
	87 06 16	3 + 608.5	MTC	2.475	2.595	4.6	16.9	5.36	9608	8.2
	87 06 17	Road	HO	2.479	2.596			5.24	10534	8.3
2 (Esso)	87 06 19	Plant	HO	2.480	2.595	4.4		5.22	12883	10.3
3 (Shell)	87 06 17	4 + 700	MTC					4.04		
		4 + 900	MTC					4.51		
		Plant	HO	2.442	2.657	8.1		4.08	10961	8.9
			PC	2.462	2.666	7.7			14429	
4 (McAsphalt)	87 06 17	5 + 006	Trow					4.43		
		5 + 416	MTC	2.403	2.625	7.7	18.1	4.00	9568	9.5
		Plant	HO	2.469	2.607	5.3		4.99	13642	10.6
			PC	2.490	2.615	4.8			15034	13.2
5 (RSR)	87 06 17	5 + 614	Trow					3.90		
		5 + 970	Trow					3.80		
		5 + 970	MTC	2.462	2.652	7.2	16.3	4.19	11575	9.6
	87 06 19	5 + 629	Trow					5.17		
		Plant	HO	2.446	2.595	5.7		5.04	11315	9.9

* Laboratories: HO - Head Office, Downsview, MTO - on-site mobile; Trow - on-site mobile

TABLE 7: MARSHALL TEST DATA

Test Section	1 Control				2 Esso				3 Shell				4 McAsphalt				5 R & S RSR			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
Tested by Laboratory																				
Specific Gravity*																				
- bulk	2.479	2.504	2.512	2.475	2.480	2.513	2.522	2.494	2.442	2.470	2.461	2.462	2.469	2.494	2.499	2.490	2.446	2.504	2.498	2.488
- maximum	2.596	2.604	2.600	2.600	2.595	2.586	2.593	2.589	2.657	2.658	2.649	2.666	2.607	2.609	2.603	2.615	2.595	2.589	2.606	2.599
Air Voids, % vol		3.84	3.4	4.8	4.4	2.82	2.7	3.7	8.1	7.07	7.1	7.7	5.3	4.41	4.0	4.8	5.7	3.36	4.1	4.3
VMA, % vol		15.9	14.6	16.8		15.6	14.6	15.8		15.8	15.1	19.6		16.1	15.2	16.9		16.1	15.3	16.4
Marshall Stability, N**	10534	18356	18851		12883	12357	11363		10961	11252	19007		13642	13223	10844		11315	11520	9897	
Marshall Flow, 0.25 mm	8.3	9.3	10.1	13.3	10.3	11.7	10.5	13.2	8.9	10.0	12.0	10.5	10.6	11.7	11.0	13.2	9.9	10.2	10.5	13.2
Asphalt Content, % wt.	5.24	5.21	5.03	4.9	5.22	5.39	5.33	5.4	4.08	3.93	3.83	4.0	4.99	4.98	5.07	4.8	5.04	5.54	5.06	4.8

* Laboratory B: density, $\times 10^3 \text{ kg/m}^3$

** At 60°C, 60 blows each face

TABLE 8: GRADATION OF EXTRACTED AGGREGATES

Sample Description Test Section Sieve Analysis		Mix Design	Control 1	Esso 2	Shell 3	McAsphalt 4	RSR 5
Sieve Size (mm)	Tested By Lab			% Passing			
9.5	A	82.0	84.0	80.0	82.0	84.0	83.0
	B		81.0	85.0	85.0	83.0	84.0
	C		83.3	78.9	85.2	81.6	82.9
	D		81.6	81.3	82.8	79.4	80.1
4.75	A	47.6	51.7	49.1	4.95	50.1	50.7
	B		46.6	49.2	48.1	46.4	50.3
	C		47.5	47.3	46.6	48.8	49.5
	D		47.0	47.6	48.6	46.3	45.4
2.36	A	41.0	45.0	41.0	43.0	42.0	44.0
	B		40.5	41.3	41.2	39.3	43.0
	C		41.1	40.0	40.1	41.9	42.1
	D		40.9	40.7	42.0	38.9	39.1
1.18	A	35.0	39.0	35.0	37.0	36.0	38.0
	B		35.4	35.2	35.6	33.7	37.1
	C		36.2	33.6	34.8	35.0	35.5
	D		35.5	34.6	36.3	33.0	33.6
0.6	A	27.0	28.0	26.0	27.0	26.0	28.0
	B		26.0	25.9	25.7	24.7	26.6
	C		25.3	24.2	24.9	25.6	23.5
	D		26.4	25.9	26.6	24.6	25.5
0.3	A	14.0	12.0	12.0	11.0	12.0	11.0
	B		11.2	12.2	10.8	11.3	11.2
	C		10.1	10.3	10.2	11.4	8.4
	D		10.5	11.6	10.4	10.9	10.5
0.15	A	4.0	4.0	4.0	4.0	4.0	4.0
	B		3.3	3.8	3.3	3.1	3.4
	C		2.4	2.6	2.7	3.0	2.0
	D		3.0	3.4	2.9	3.0	3.1
0.075	A	0.9	1.1	1.0	1.1	1.2	1.2
	B		1.2	1.5	1.3	1.0	1.4
	C		0.7	2.6	1.0	0.9	0.7
	D		1.1	1.3	1.1	1.1	1.1

TABLE 9: CORES FROM MODIFIED ASPHALT TEST SECTIONS

Core No.	Trial Section	Station	Distance (m)*	BRD	Compaction %	Comments
1A	1 (control)	3 + 640.7	2.02	2.378	95.9	face cracked, piece missing on side
B		3 + 790.7	2.02	2.356	95.0	face cracked, piece missing on side
C		4 + 039.3	3.40	2.438	98.3	Pieces missing from bottom
2A(B1)	2 (Esso)	4 + 249	2.50	2.482	100.0	
B(B2)		4 + 351	2.60	2.469	99.6	
C(RC)		4 + 463	1.70	2.445	98.6	
3A	3 (Shell)	4 + 862.4	1.87	2.356	96.5	
B		4 + 997	2.06	2.392	98.0	top is rough
C		5 + 192.3	2.02	2.391	97.9	crack on bottom
4A	4 (McAsphalt)	5 + 382.4	1.92	2.392	96.9	
B		5 + 536.3	1.87	2.360	95.6	
C		6 + 082.1	3.83	2.406	97.4	
5A(C1)	5 (RSR)	5 + 737	2.40	2.449	100.0	cracked and warped
B(C2)		5 + 756	2.30	2.420	98.9	
C(C3)		5 + 198	2.00	2.474	101.1	

* Distance from right edge of pavement

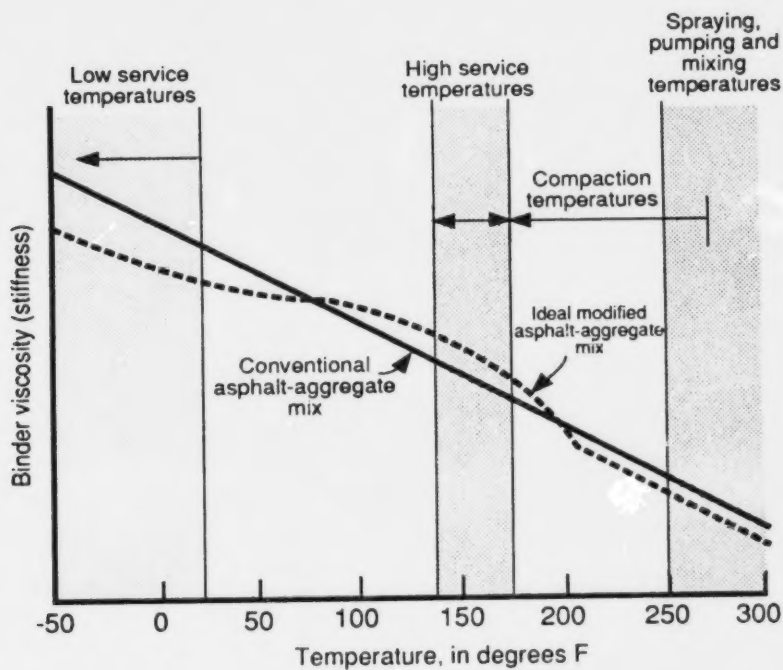


Figure 1/ Stiffness of Asphalt Binders

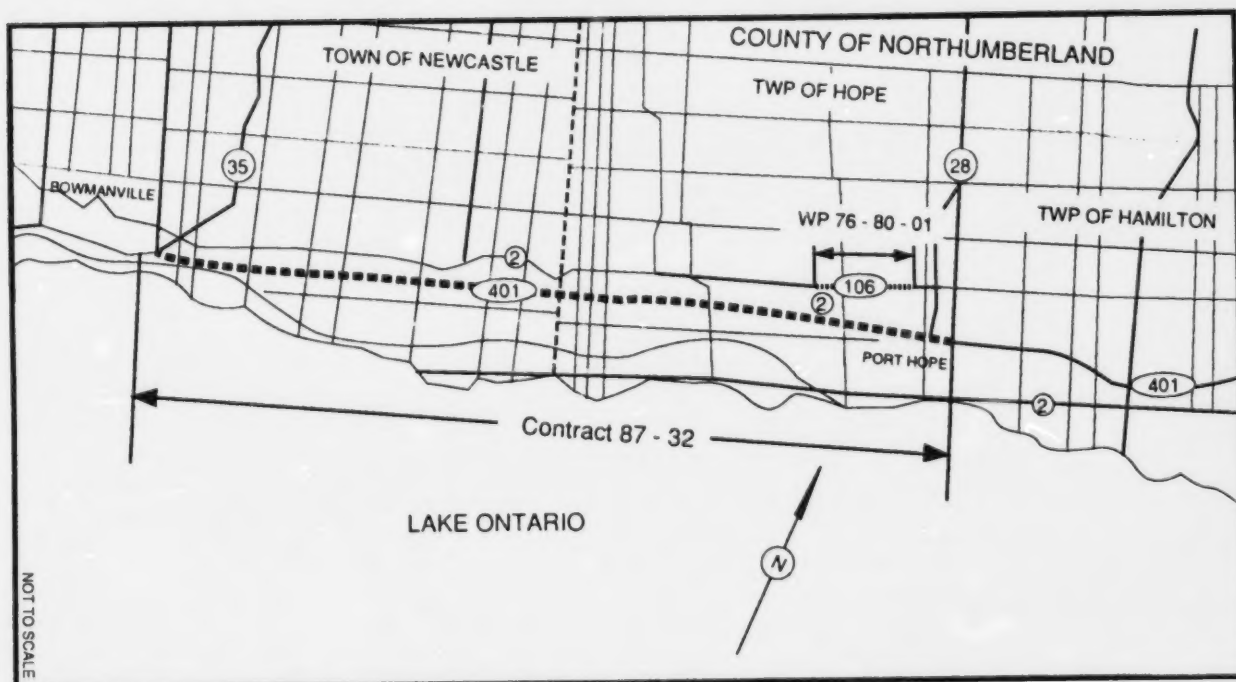


Figure 2/ Project Location Map



**Figure 3/ Typical Severe Wheel Track Rutting
(27 mm) of Eastbound Driving Lane**



Figure 4(a)/ Typical Severe Pavement Distress



Figure 4(b)/ Typical Transverse Crack

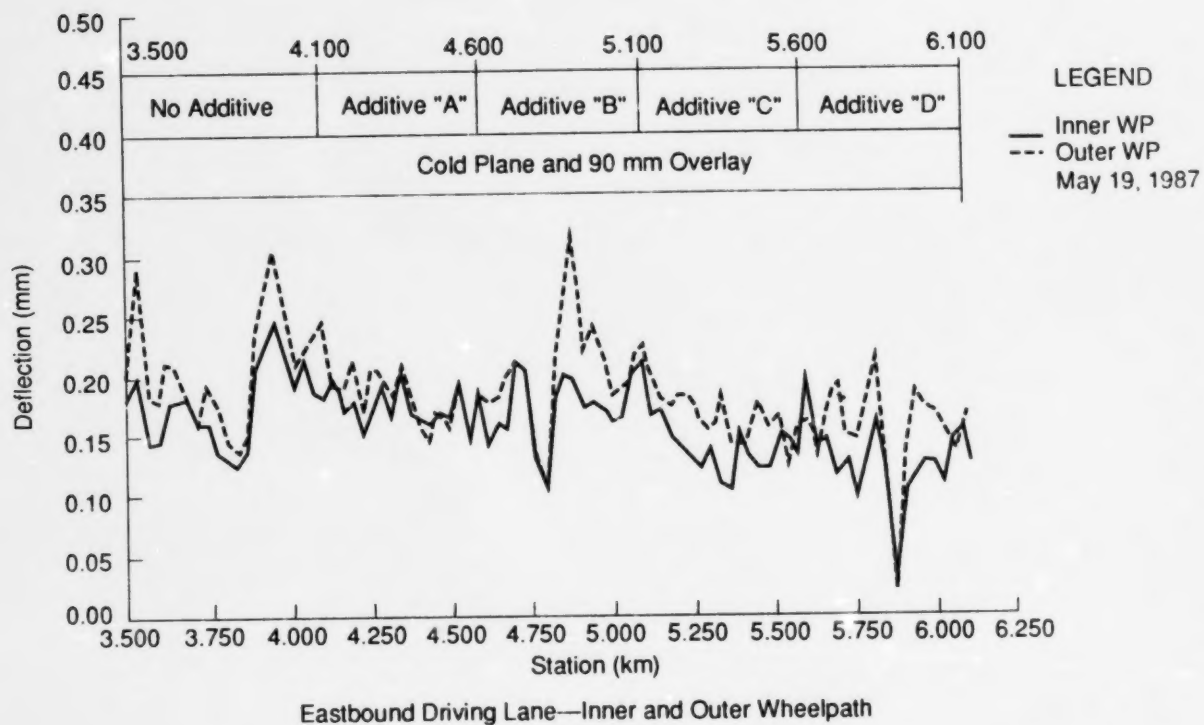


Figure 5/ Normalized FWD Deflections vs. Roadway Chainage
(Highway 401 East of Highway 35/115)

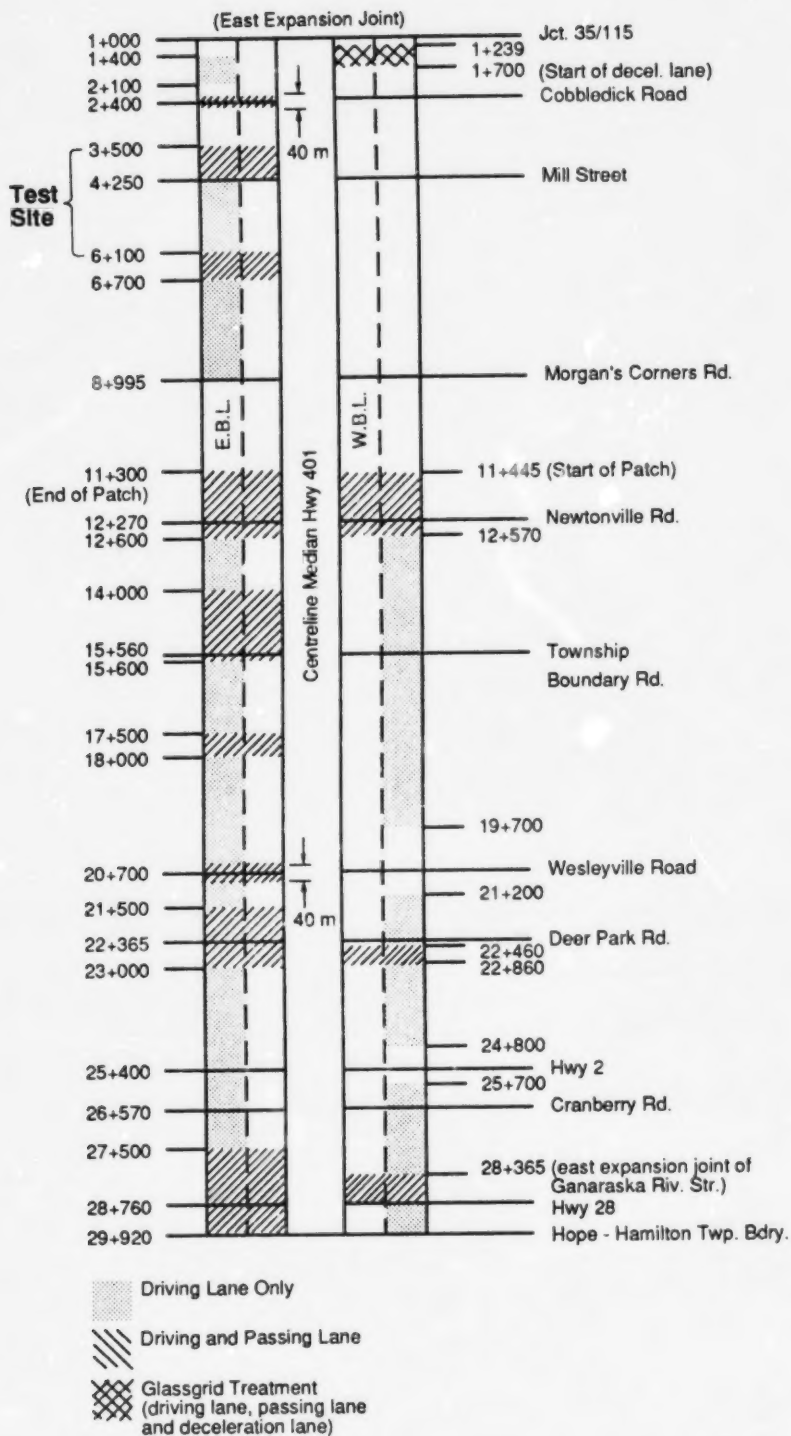


Figure 6/ Proposed Treatment Areas

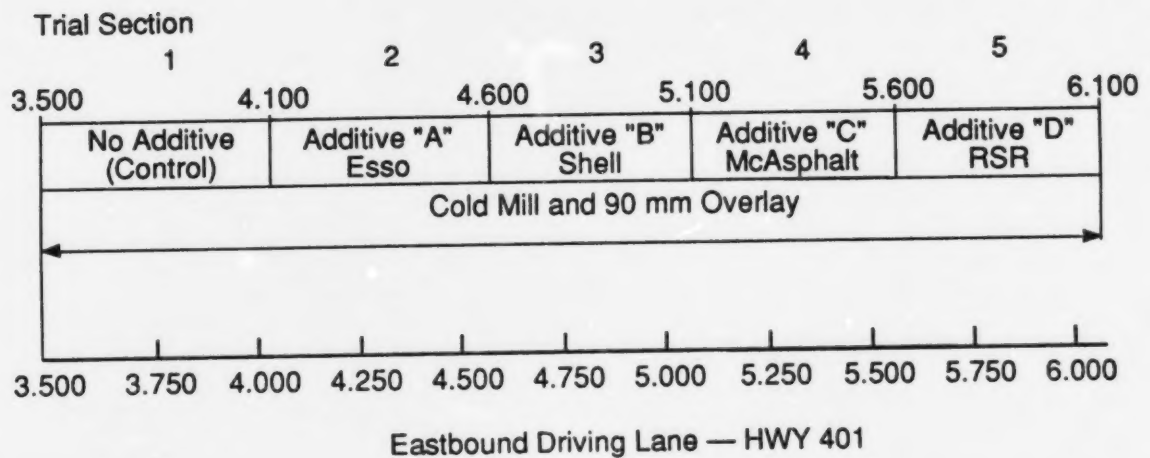


Figure 7/ Trial Section Layout

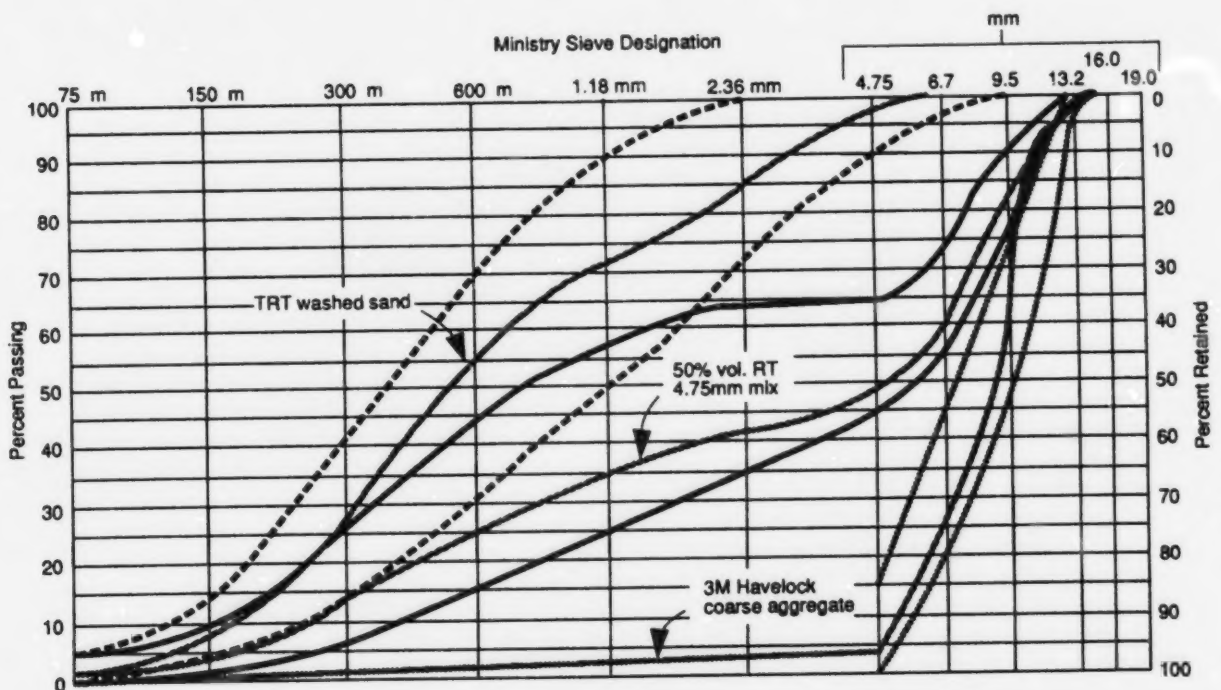


Figure 8/ Semi-Log Grading Chart
(Mix Design Contract 87 — 32)



Figure 9/ "Force Ductility" — Picking up a Spill



Figure 10(a)/ Eastbound Driving Lane after Removal of 90 mm Pavement



Figure 10(b)/ Laying of Polymer-Modified Binder Course (40 mm)

Appendix A

**Condition Survey of Pavement Surface
(Contract No. 87-32, Station 3.500 to 6.100)**

MINISTRY OF
TRANSPORTATION AND COMMUNICATIONS
RESEARCH AND DEVELOPMENT BRANCH

SHEET NUMBER
1 OF 5
SCALE
1 DIV = 1 m

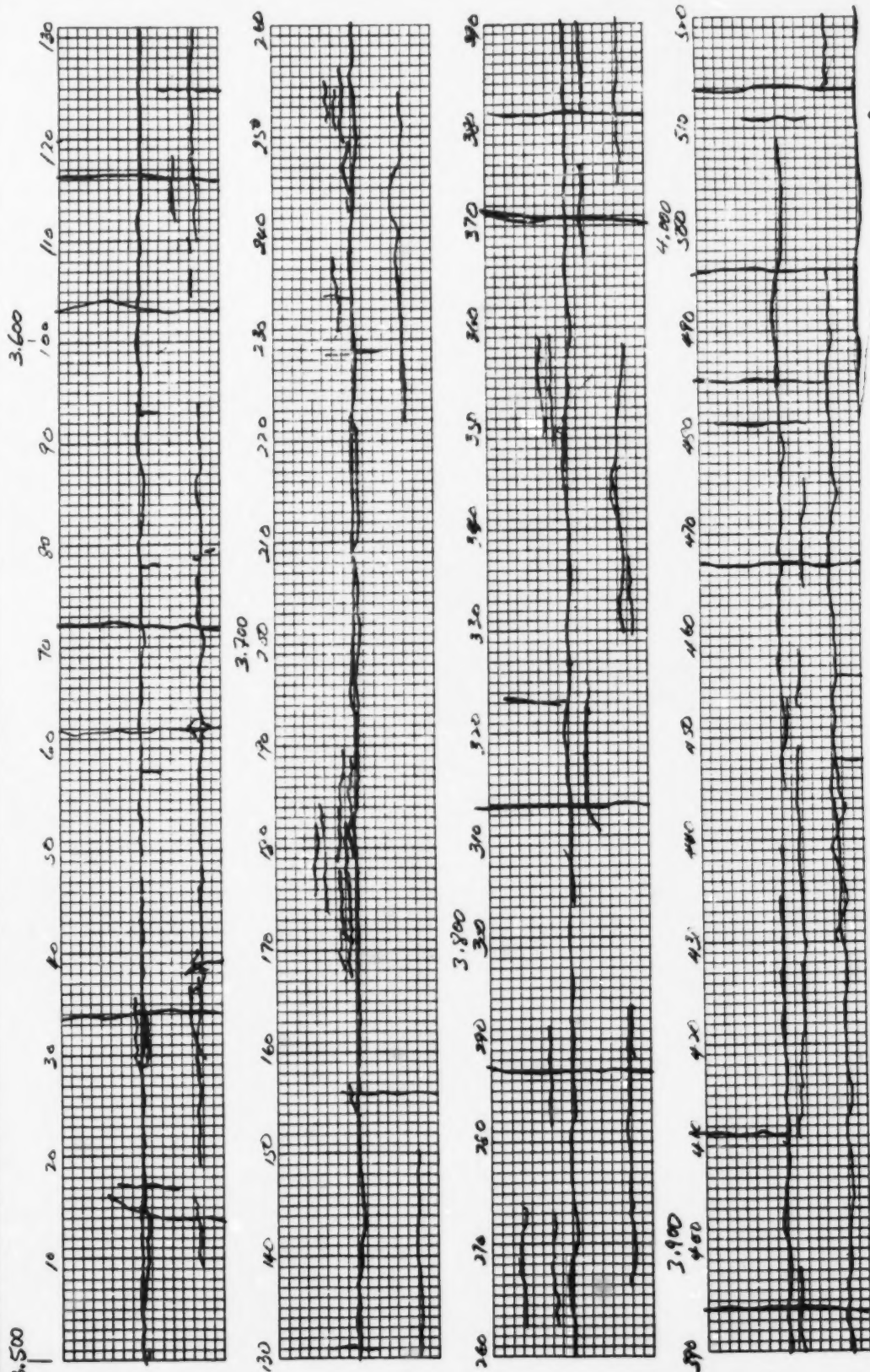
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CONDITION SURVEY OF PAVEMENT SURFACE

Lane 2 Only

HWY. NO. 401

Sta 3,500



Ramp → Mill Stree

REMARKS

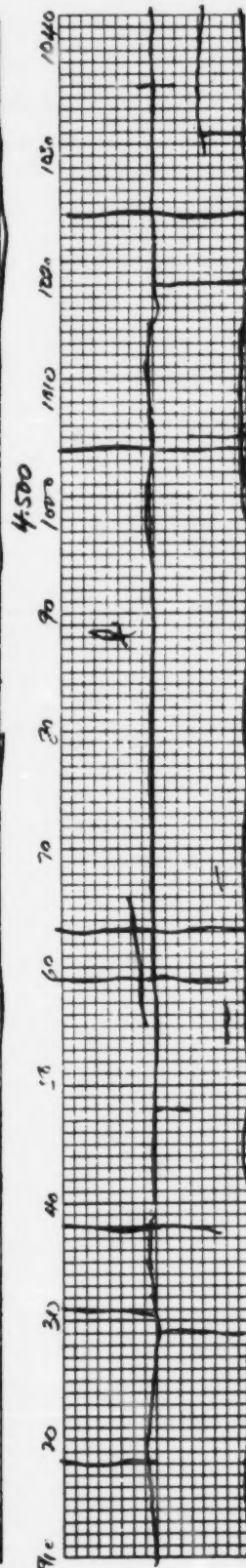
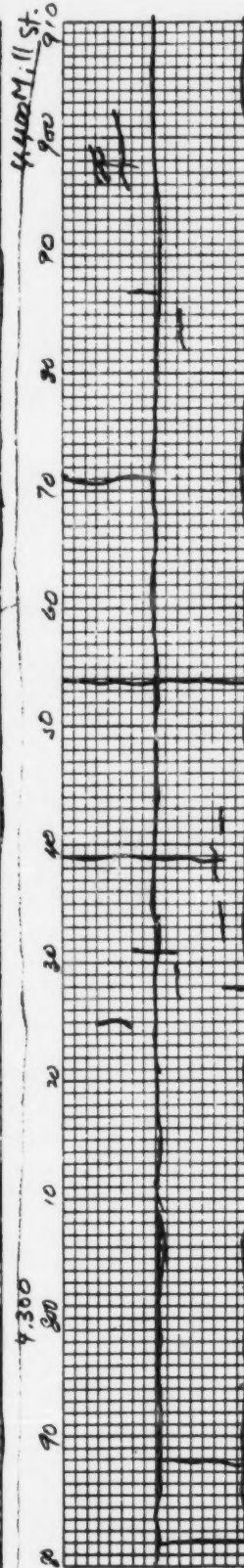
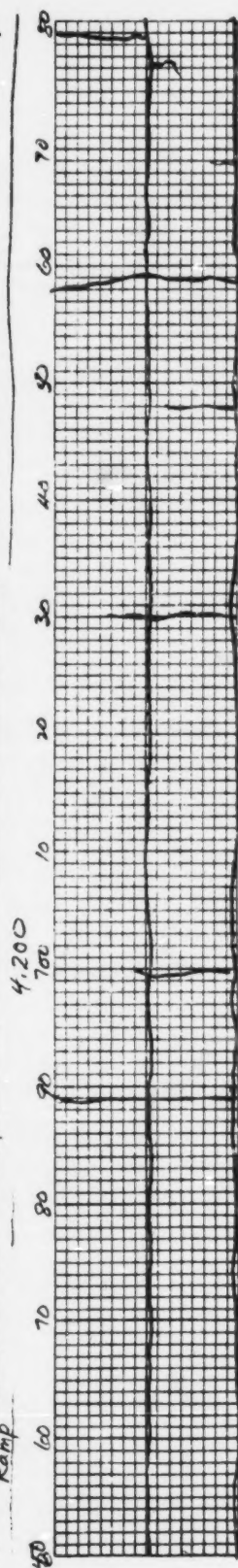
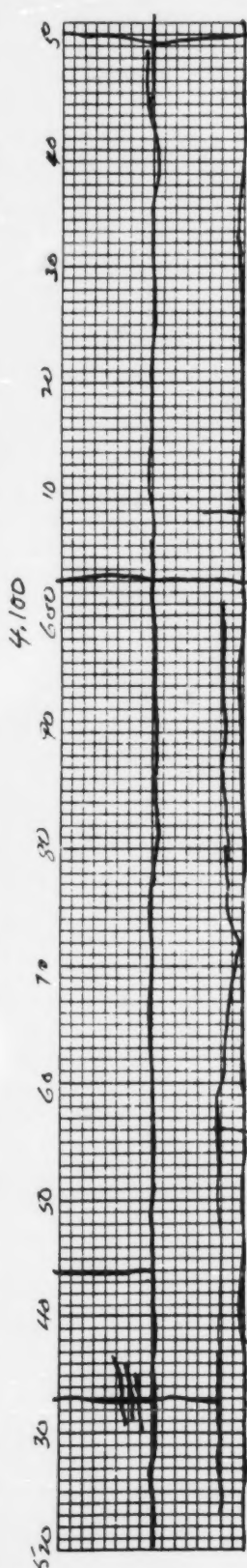
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TRANSPORTATION AND COMMUNICATIONS
RESEARCH AND DEVELOPMENT BRANCH

CONDITION SURVEY OF PAVEMENT SURFACE

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HWY. NO. 401 / #87-32

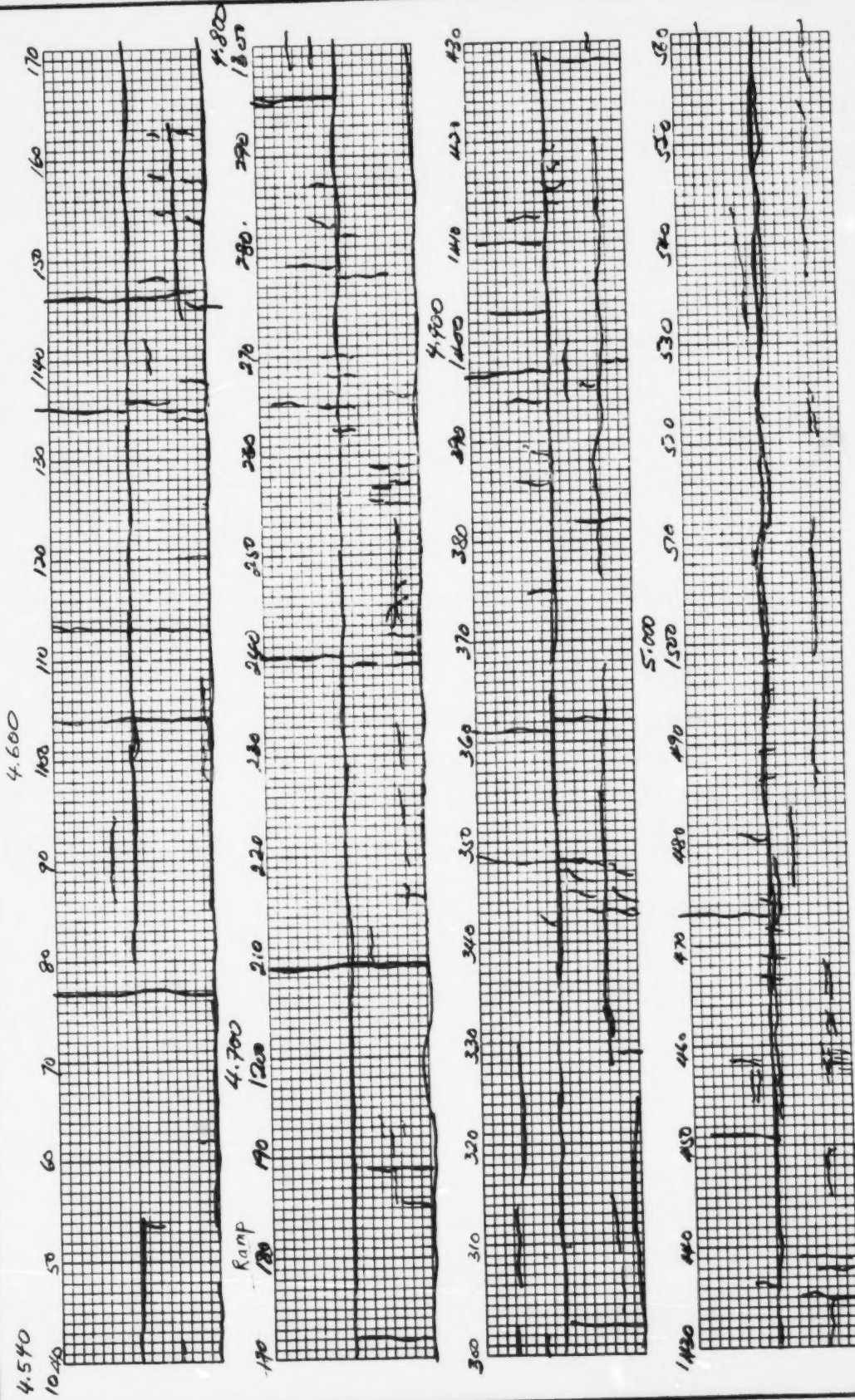


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3 OF 5
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RESEARCH AND DEVELOPMENT BRANCH
CONDITION SURVEY OF PAVEMENT SURFACE

HWY. NO. 401 / #87-32



DATE OF SURVEY 87-05-19

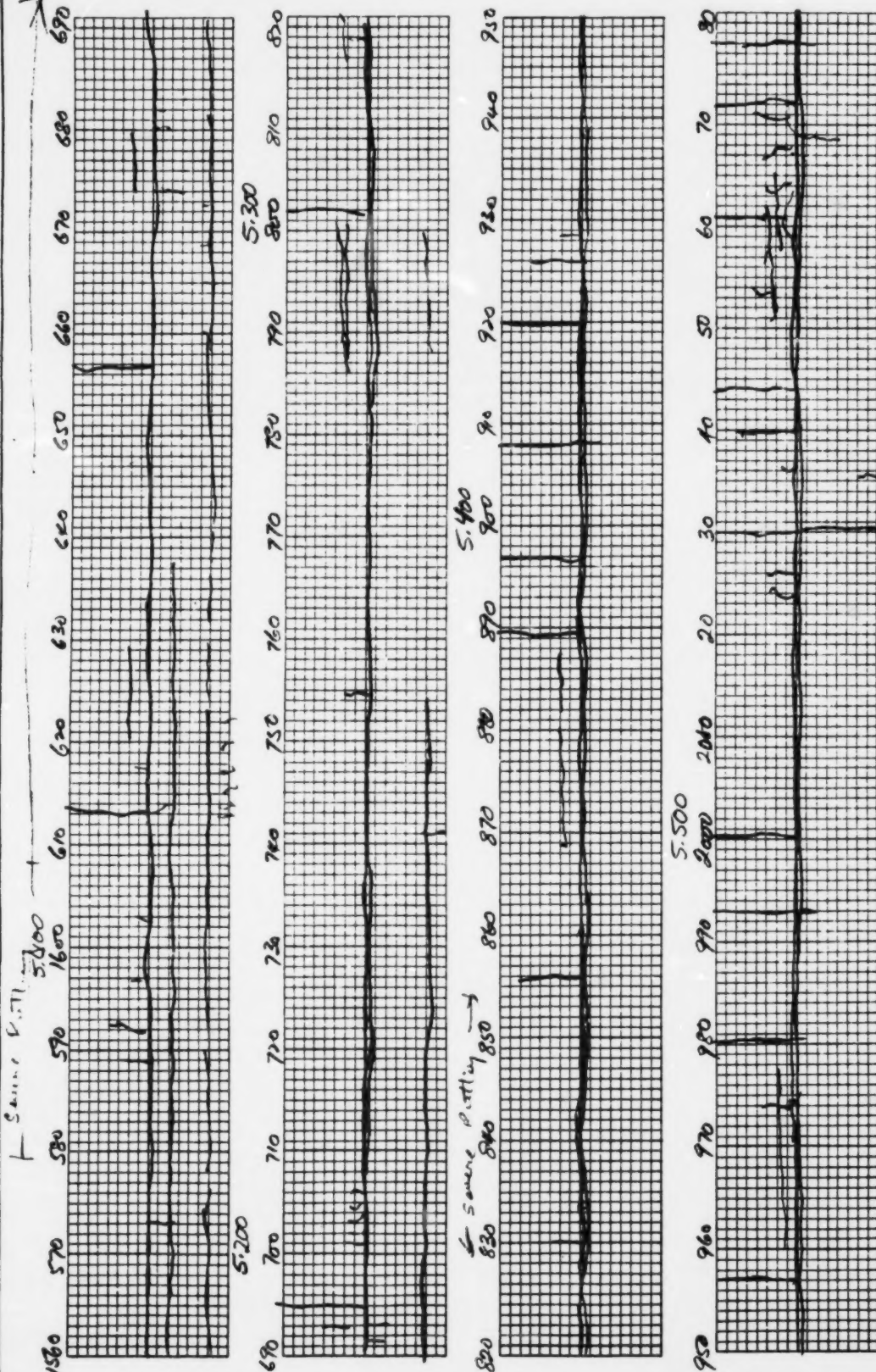
REMARKS

MINISTRY OF
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RESEARCH AND DEVELOPMENT BRANCH

SHEET NUMBER
4 OF 5
SCALE
1 DIV = 1 m

CONDITION SURVEY OF PAVEMENT SURFACE

HWY. NO. 401 / #87-32



REMARKS

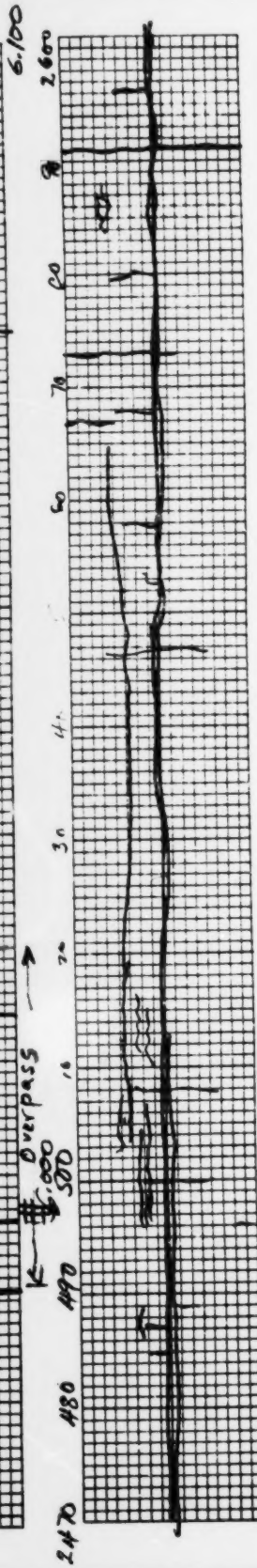
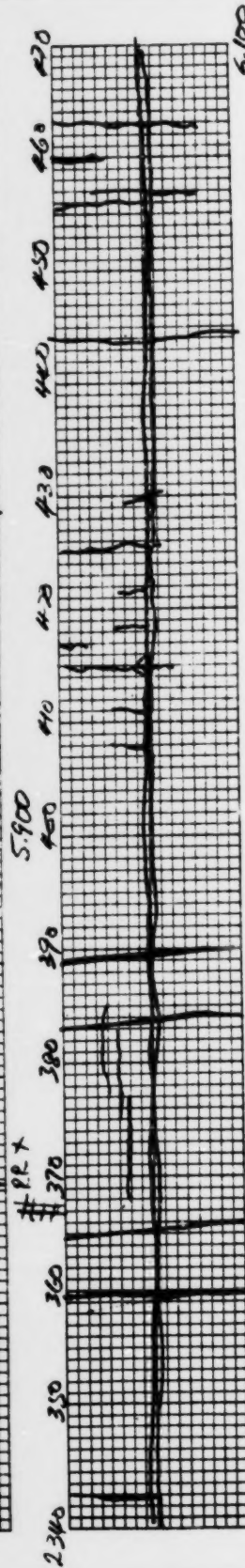
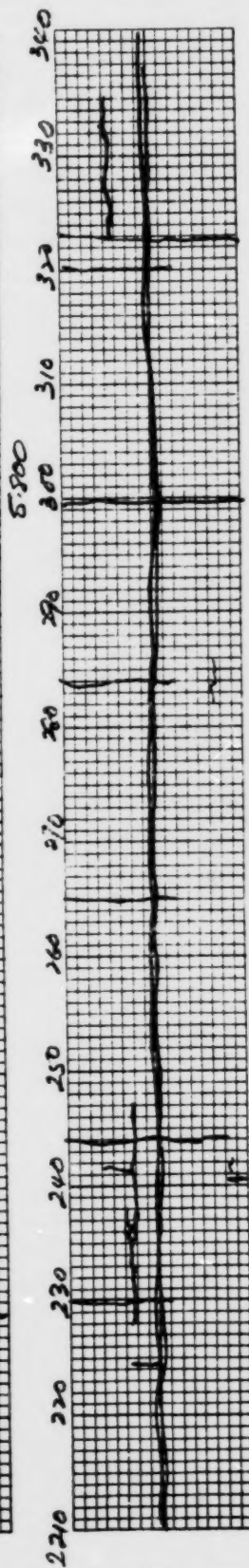
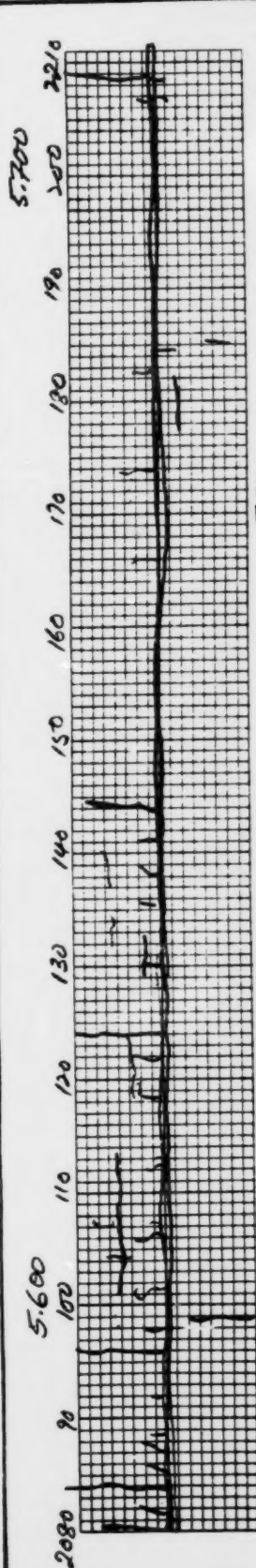
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SHEET NUMBER
5 OF 5

SCALE
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TRANSPORTATION AND COMMUNICATIONS
RESEARCH AND DEVELOPMENT BRANCH
CONDITION SURVEY OF PAVEMENT SURFACE

HWY. NO. 401 / #87-32



DATE OF SURVEY 87-05-19

REMARKS